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ABSTRACT

To better understand construction's impact, an overview of building ecology as a concept and as a decision-making model for school systems is provided. "Building ecology" is defined as the interrelationships among people, the built environment, and the natural environment. It has special relevance for school design because most of the users are children; therefore it is important that administrators fully understand the types of materials used in building schools. A material's energy efficiency can be important, as is the lifecycle of any material. A decision-making model is presented, which offers a step-by-step process for determining the best materials to use. How to choose flooring is featured as an extended example of this process. The environmental issues connected with various flooring such as vinyl composition tile, linoleum flooring, carpet, terrazzo, wood flooring, and ceramic tile are detailed. A hypothetical material selection process is offered, along with general recommendations in choosing, installing, and maintaining flooring. (Contains 13 references.) (RJM)

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Technical Bulletin

Building Ecology & School Design

November 1995

Maryland State Department of Education
Division of Business Services,
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Maryland State Department of Education

Technical Bulletin

Division of Business Services, School Facilities Branch
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Building Ecology & School Design

November 1995

Technical Bulletin Intent

This technical bulletin provides both an overview of building ecology as a concept and a decision-making model for school systems, facility planners and architects to incorporate environmentally sound practices into building decisions. The decision-making framework is illustrated by its application to a specific aspect of school design: flooring material selection.

Defining Building Ecology

All acts of building have environmental consequences. Building ecology is a term that describes "the interrelationships between people, the built environment, and the natural environment." This concept is broad enough to include both macro- and micro-scale issues from global environmental concerns to regional planning to indoor environmental health effects. In the broadest terms, building ecology may include consideration of:

- atmospheric impacts
- water use and water quality
- resource conservation and depletion
- biodiversity conservation and reduction
- human health effects
- energy use
- land use
- waste generation
- soil pollution
- socioeconomic impacts.

Current design practice typically considers systems and materials based on point-of-use criteria: how much does the material cost, how does it look, and what are its performance capabilities? Secondary criteria, such as replacement frequency, energy use, and maintenance costs, are often factored into the material selection process for school design. Indoor air quality is increasingly recognized as a secondary factor in school design, and is often the first introduction of building ecology to the process. Building ecology adds external environmental criteria, examining the environmental costs of building materials and systems from the acquisition of raw materials through disposition after their intended life is over. This long-term view is often called a "cradle to grave" perspective. A more environmentally responsible concept is cradle to cradle, since used materials may become resources for new materials. Building ecology assists designers in their attempts to identify and minimize the negative impacts of the built environment on the planet.

Building Ecology and School Design

Building ecology has special relevance for school design because our end-users are predominantly children and our mission is education. Children are more susceptible to adverse effects from indoor environmental pollution than adults. A safe and appropriate learning environment enhances the educational process. While the immediate health and safety of our children are the most direct factors, broader issues are also important. We teach students critical thinking skills so they may make informed decisions about themselves, society, and the environment. Those of us who make decisions for students must hold ourselves to the same standard. We are the stewards of the environment they will inherit.

Understanding Building Ecology

The construction and occupancy of buildings has a tremendous impact on the environment. For example, building-related energy use accounts for 40 per cent of the total energy consumption in the United States. (See Figure 1 on page 2.) Architects are increasingly presented with information about "green" building materials from manufacturers, consultants, professional organizations, and others, or with assurances from familiar product manufacturers that the products they sell are already "green." Often promotional information highlights the advantages of one material over another by looking at carefully selected aspects of each. Standardized measures of environmental impacts are not widely available. Different impacts may be ranked as more or less significant by different communities. Based on the incomplete information available today, what responsible action can a school system take to improve the ecological performance of its buildings? What additional information is needed in order to make fully informed decisions? How can architects and facility planners filter technical information and marketing claims to determine the environmental value of building materials and compare alternatives?

Many efforts are under way to improve the environmental performance of building materials and to communicate environmental information in consistent and understandable language. Some changes originate with individual manufacturers or industry groups; others originate with environmental organizations. Governments are also playing an important role, both through regulatory mechanisms and the development of voluntary consensus-driven standards and guidelines. Third party and non-profit guidelines and certification programs are also under development.

Several building industry manufacturers and manufacturer's associations are developing voluntary industry standards. Among the first to develop voluntary standards was the carpet industry. The Carpet and Rug Institute has developed a carpet certification program. Carpets are evaluated for total and specific volatile organic compound emission levels; those that meet the pre-set criteria are "certified" and receive a label that consumers can look for. While not guaranteeing a safe carpet, the program provides a measure of assurance that emissions are being monitored. More recently, the American Forest and Paper Association developed the Sustainable Forestry Initiative for member companies. While some standards may be developed primarily as public relations tools, others represent promotion of best practices and quality control. One way to tell the difference is through third party certification, where private fee-for-service companies certify products based on explicit criteria. For example, Scientific Certification Systems of California verifies and certifies specific environmental claims or provides an overall environmental report card based on a cradle to grave analysis. Some certifiers specialize in one area or industry, for example, SmartWood certifies wood based on sustainable forestry practices.

Professional organizations, such as the American Institute of Architects (AIA), are developing resources for understanding building ecology. The AIA *Environmental Resource Guide* (ERG), available on a subscription basis, uses a lifecycle analysis

Figure 1. Impacts of Modern Buildings on People and the Environment

Problem	Buildings' Share of Problem	Effects
Use of Virgin Minerals	40 percent of raw stone, gravel, and sand; comparable share of other processed materials such as steel	Landscape destruction, toxic runoff from mines and tailings, deforestation, air and water pollution from processing
Use of Virgin Wood	25 percent for construction	Deforestation, flooding, siltation, biological and cultural diversity losses
Use of Energy Resources	40 percent of total energy use	Local air pollution, acid rain, damming of rivers, nuclear waste, risk of global warming
Use of Water	16 percent of total withdrawals	Water pollution; competes with agriculture and ecosystems for water
Production of Waste	Comparable in industrial countries to municipal solid waste generation	Landfill problems, such as leaching of heavy metals and water pollution
Unhealthy Indoor Air	Poor air quality in 30 percent of new and renovated buildings	Higher incidence of sickness—lost productivity in tens of billions annually

Roodman and Lenssen. A Building Revolution: How Ecology and Health Concerns Are Transforming Construction. Washington, D.C.: World Watch Institute, 1995

approach along with case studies to inform the design profession about building ecology. Other publications such as *Environmental Building News* and *Healthy Materials* (Canada) provide in-depth analysis of complex issues.

The Federal Trade Commission's Environmental Marketing Guidelines say that general environmental benefit claims should be substantiated, "avoided or qualified, as necessary, to prevent deception about the specific nature of the environmental benefit being asserted." Terms covered by the Guidelines include:

- **Degradable, biodegradable, and photodegradable**
- **Recyclable**
- **Recycled content**
- **Source reduction**
- **Ozone safe and ozone friendly**

The FTC says that "any time marketers make objective environmental claims—whether explicit or implied—they must be substantiated by competent and reliable...scientific evidence."

Building assessment programs evaluate proposed or existing buildings based on explicit environmental criteria. The Building Environmental Performance Assessment Criteria (BEPAC) of British Columbia and the Building Research Establishment Environmental Assessment Method (BREEAM) of the United Kingdom are two examples. Both of these programs rely on the marketplace for incentives, under the assumption that environmentally friendly buildings can command higher rents or resale value than buildings constructed or managed without specific regard to the environment. Several studies of worker productivity support this rationale.

Government agencies have developed or are developing guidelines for environmental performance or claims about performance. The Federal Trade Commission (FTC) has released guidelines on environmental marketing claims (see box). The National Institute of Standards and Technology (NIST) has a publicly accessible database, highlighting quantitative information on environmental impacts of building materials. It is expected to be available in 1997. Decision support software will accompany the data. The American Society for Testing Materials (ASTM) Committee E50 is drafting standardized methods for environmental lifecycle assessment of building materials.

Many state and local governments are developing performance standards or certification programs. Washington and California have programs in place or under development. The city of Austin, Texas, supports improved building ecology through its Green Builder Program, which certifies builders based on community-generated goals and priorities. In addition to these efforts in the United States, several other countries have active programs. Canada and Denmark are widely cited for their work on the indoor environment. The aim of many of these efforts is to establish consistency in the quantification and qualification of environmental impacts.

Lifecycle Analysis

One evaluation tool often cited is a lifecycle or "cradle to grave" analysis. Adverse environmental impacts may occur at any point in the life of a building and its component materials. A lifecycle analysis is a chronological framework for understanding these impacts. (see Figure 2 on page 3)

Stages in a Lifecycle Analysis:

A. Materials Acquisition and Manufacturing

Raw materials acquisition. Are materials from renewable or sustainable sources? If not, are the resources in short supply? Can they be removed without negative impacts to surrounding areas? Are any of the raw materials recycled from a previous use?

Manufacturing processes. The environmental impacts of manufacturing processes are complex and varied. Some common concerns include energy consumption, water use, air and water pollution, ozone depletion, acid rain, and worker safety. What waste is generated and how is it disposed? Have communities near manufacturing plants suffered from health problems attributable to the manufacturing plant?

Transportation. Are materials acquired and processed locally? If not, how much fuel is used in transportation? What are the resource and pollution impacts of the fuel use? Are there other environmental hazards associated with transportation?

B. Installation and Useful Life

Installation. The environmental impacts of a building material are sometimes significant during installation, especially for products requiring solvent-based application. Volatile organic compound (VOC) emissions and particulate pollution are two common concerns. Safety for workers and occupants is an important consideration during installation.

Information needed to compare materials emission test results:

- **Age and source of sample**
- **Preparation of sample**
- **Chamber conditions**
- **Decay rates over time**

(Summarized from *Healthy Materials*, a newsletter published by the Canada Mortgage and Housing Corporation)

Indoor air quality. In addition to VOC emissions during installation, emissions during the life of a material can impact occupant health. Total VOCs (TVOC) as well as specific VOCs and their emissions over time should be considered. Consistent data for alternative choices are difficult to find. Combinations of materials can have synergistic effects which are not yet well understood.

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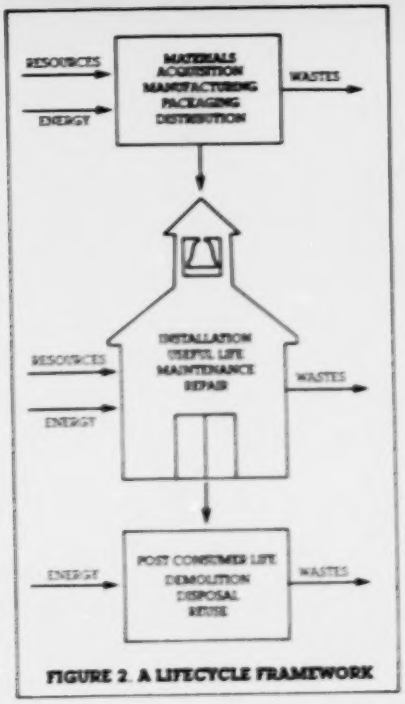

FIGURE 2. A LIFECYCLE FRAMEWORK

Porous materials may adsorb VOCs from other materials and subsequently offgas these substances longer than the source material.

Maintenance ecology. Any material under consideration for use in a school should be maintainable with products and procedures that have no or minimal harmful impact on the environment.

Durability. Durability is a factor in building ecology because all the environmental impacts associated with the acquisition, manufacture, and installation of a product represent an environmental investment that can be amortized over time. For example, if flooring product *A* uses twice as much energy as product *B* to produce and install, but lasts three times longer, then the energy investment over time is less for product *A* than for product *B*. Another factor affecting durability is reparability. Can the life of a product be extended through repair?

C. Post-Consumer Life

Demolition hazards and disposal issues. Once a building material is no longer fit for its original use, it still has environmental impacts. Does a material become hazardous waste once removed? Is it recyclable? Is there a post-consumer market for it? Does it biodegrade?

Choosing Among Materials

A Decision-Making Model

The lifecycle outline and the questions it raises hint at the complexity of environmental impact analysis for materials. As researchers fill in the outlines with data and analysis, architects and facility planners can begin to make informed decisions. The decision-making process can be nearly as complex as the materials themselves, however.

There are no perfect building materials and there are many factors that are unknown or not yet understood. For example, two competing materials may embody equal amounts of energy. Yet one may be manufactured at a plant that buys power from a renewable, clean fuel source, while the other may be manufactured at a variety of plants, some of which buy fuel from a more polluting utility plant. This kind of information is not available at present. In another case, two different materials may emit a similar quantity of TVOCs, but neither manufacturer will release the identity of specific VOCs within the emissions. In a third example, a promising material may be made using renewable materials, but it must be installed using solvent-based adhesives. How does an architect weigh the different impacts against each other? And how do decision-makers compare information where sources are not parallel?

The following steps outline a decision-making model for school projects that can work within today's limitations. Once outlined, the process will be applied to the selection of flooring materials.

Steps

1. Start out modestly by focusing on a few materials that have a great impact on the environment. For example, wall finishes and flooring have a great impact on the indoor environment. Share criteria with the project planning committee, as you would conventional design alternatives. The committee might include teachers, students, parents, maintenance staff, project architects, representatives of funding agencies, and others. As the selection process progresses, recognize imprecision where it exists. Most answers reached with today's knowledge will not be outright, but that doesn't mean significant improvements to the environmental performance of building materials are not readily achievable.

2. Establish an intended life span for the project. A school building may stay in service for 40 to 100 years or longer. Understanding the intended life span will be useful in evaluating the investment of natural resources, as well as money over time, some materials that appear to be expensive at first glance are sound investments over the life of a building.

3. Establish a set of material options. Each should be considered within the context of the whole project and should meet traditional (non-environmental) performance requirements for its intended use. Identify assemblies, such as carpet, backing, adhesive, and seam sealers, rather than individual components. Collect available data for each assembly. Try to assemble the following information: a raw materials list, embodied energy, TVOCs, important VOCs, life expectancy, manufacturers' safety data sheets (MSDS), and installed costs. If maintenance costs are available, those can be very helpful. Ask manufacturers if they have an environmental policy. Many do. This list does not approach a complete lifecycle analysis, but emphasizes a few key measures where information may be available.

4. Eliminate materials that don't meet your traditional performance requirements. For example, materials that will not be durable enough for use in schools should not be considered, even if they are environmentally benign.

5. Apply numerical values to the data collected. The values proposed below are for illustrative purposes and exclude some important criteria. As information becomes more widely available, a more refined process can be developed.

   A. **Raw material sources**, including recycled content (as a percentage of weight or volume). Score as follows: 1 = 100% finite resources in limited supply; 2 = finite resources mostly in abundant supply; 3 = renewable resources, not sustainably managed; 4 = renewable resources, sustainably or restoratively managed.

   B. **Embodied energy over time** in BTUs per square foot, per cubic foot, or per pound as appropriate; the scale for this criterion will vary with the type of material. (values in parentheses are for the flooring study which follows). Score as follows: 1 = high embodied energy (greater than 1000 BTUs per square foot per year), 2 = medium-high (300 to 1000 BTUs per square foot per year), 3 = medium-low (100 to 300 BTUs per square foot per year), 4 = low (less than 100 BTUs per square foot per year).

   C. **TVOCs** and test protocol for emissions testing at one to four points in time for interior finish materials. The consecutive results can be plotted on a curve suggesting flush-out requirements and installation order. W. Gene Tucker has proposed a classification system for low-emitting materials (see references). Based on his parameters, scoring might be as follows (emission rates in parentheses are used for flooring in example below): 1 = medium-high emitter (0.4 to 0.6 mg/h per m²); 2 = medium emitter (0.2 to 0.4 mg/h per m²); 3 = low-emitter (0.1 to 0.2 mg/h per m²); 4 = very low or non-emitter (TVOCs < 0.1 mg/h per m²). For flooring, eliminate from consideration any flooring system with TVOCs greater than 0.6 mg/h per m².

   D. **Life expectancy**. Score as follows: 1 = short life expectancy (1/4 or less of building's intended life); 2 = medium life expectancy (1/2 of building's intended life); 3 = medium to long life expectancy (3/4 of

building's intended life) 4=long life expectancy (material life ≥ building's expected life).

E. **MSDS** for each component, as well as for the manufacturer's recommended finishing and cleaning products where appropriate. The number of possible concerns indicated by an MSDS is great. Scoring is difficult and may not be useful in all cases. Eliminate any materials that contain harmful levels of toxic substances as defined by the International Agency for Research on Cancer, the National Toxicology Program, NIOSH, or the *Catalogue of Teratogenic Agents*. These references can define exposure thresholds for specific substances. Score as follows: 1=raises substantive safety concerns for installers and occupants. 2=raises substantive health concerns only during well-defined phases, such as installation and finishing, when children will not be present and procedures to protect workers are to be implemented. 3=raises minor health concerns only during installation when installers can be protected and children are not present. 4=the MSDS does not indicate any concerns.

F. **Cost** per unit area over time. Divide the installed and maintained unit cost by the expected life of the material. If energy costs are known for all options, those can be factored in. Score as follows (range in parentheses applies to flooring example which follows): 1=high cost ($4 to $5 per square foot per year), 2=medium-high cost ($3 to $4), 3=moderate cost ($2 to $3), 4=low cost (up to $2).

G. **First cost per unit**. Use installed costs.

6. Build a matrix using the values derived. If one or two criteria are more important than the others, apply an emphasis factor to the matrix. As configured above, the matrix favors durability as an important factor in environmental performance. Add the scores for each material to arrive at a total grade. If one material clearly receives a higher total score, then it would be the preferable material. If several materials are acceptable but close in total points, then the selection committee might look at more detailed criteria, if available, or select materials based on traditional non-environmental criteria, such as first cost or aesthetics. The matrix is not intended to imply a false level of precision. Ultimately, as uniform assessment methods are widely used and as manufacturers, and others publish more details about environmental impacts, the criteria should be revised to reflect a more complete lifecycle analysis.

Example: Building Ecology and Flooring

Over 4 billion square feet of floor space are enclosed in our existing school building stock and millions of new square feet are constructed each year. Flooring covers a significant portion of the finished surface area in a school and therefore can have a significant impact on indoor air quality. Architects, consumer groups, environmentalists, manufacturers, and government agencies have begun to assess the environmental impacts of some common flooring materials. In particular, carpet has received a great deal of attention and, to a lesser extent, vinyl composition tile (with other vinyl materials).

The analysis that follows provides an overview of available information on typical flooring materials as well as some alternative products. The flooring types considered are vinyl composition tile (VCT), carpet, terrazzo, ceramic tile, wood, and linoleum. Each material is described in terms of its environmental performance, then compared with others for a hypothetical school project using the flooring selection matrix.

Vinyl Composition Tile

General Information

A survey of recent construction projects shows that VCT is the finish of choice for up to 75 percent of school floor surfaces, amounting to billions of square feet nationally. VCT is often specified for its low first cost, ease of maintenance, and resilience. It is typically used in classrooms, multi-purpose rooms, and science labs, and is the general purpose choice for many program areas. It is often used in corridors, toilet rooms, and other high-demand locations. Sheet vinyl is less frequently specified for schools. Because its higher plasticizer content does not usually offer better environmental performance than VCT, it is not included in this bulletin.

As an assembly, a VCT flooring system consists of VCT, adhesive, and a surface coating over a subfloor. VCT is made from poly-vinyl chloride (PVC) resin, fillers, and pigments. The PVC resin, which acts as a binder, is made from natural gas or petroleum and chlorine from rock salt. It may contain other monomeric resins, plasticizers, stabilizers, and other ingredients.[3] The predominant filler may be limestone (typically over 75%).[4]

VCT costs about $1.25 per square foot installed; its life expectancy is from 15 to 33 years.

Summary of Environmental Issues

VCT is made of non-renewable resources. The extraction of natural gas and petroleum can result in damage to waterways and the release of highly toxic and carcinogenic air emissions. Limestone is an abundant, though finite, mineral. Mining for limestone causes environmental degradation, including surface and ground water pollution, as well as air pollution from dust and fossil fuel emissions from equipment.

More difficult to assess are the environmental impacts associated with PVC production, transportation, and use. Environmental groups and the PVC and vinyl flooring industry disagree about the risks associated with PVC. Section 307(a) of the Clean Water Act lists vinyl chloride as a priority pollutant (ERG). A 1988 study found a correlation between public health problems and exposure to ambient levels of vinyl chloride in communities adjacent to PVC factories.[5] The waste generated during the production of PVC is strictly regulated due to the presence of vinyl chloride monomer, a known carcinogen which was responsible for a rare cancer of the liver found in PVC workers.[6] Vinyl chloride monomer is subject to strict workplace exposure limits by OSHA, and is now stripped from PVC before its incorporation in products. Some toxic components have been replaced in recent years by more benign substances. The vinyl chloride conversion process produces hydrochloric acid as a byproduct. Environmental groups say that the toxic byproducts created during manufacturing are impossible to completely contain at all times. The American Public Health Association and others have called for the gradual phasing out of PVC where viable alternatives exist.[7] Industry spokespeople say that existing regulations and voluntary industry efforts provide adequate protection to workers and the public. VCT manufacturers emphasize that the amount of PVC in the tile is small. Available information indicates that most commercial grade VCT meets indoor air performance criteria; no specific health issues arising from its use have been detailed. In spite of the controversy, the market share for PVC construction products is steadily increasing, especially for wiring, piping, and siding, because of their low first cost and desirable performance characteristics.

Ease of maintenance is one of VCT's assets. Low-toxic and low-VOC cleaners and sealers are available. Post-consumer VCT is not biodegradable or recyclable. There is no market for post-consumer VCT.

Asbestos may be present in older VCT and adhesives. Work involving asbestos-containing materials (ACM) should be accomplished by trained personnel. The Asbestos Hazard Emergency Response Act applies to work which disturbs friable ACM. State laws may vary in regulating vinyl asbestos tile (VAT) removal. No particular hazards are associated with demolition of non-ACM vinyl flooring systems.

Linoleum Flooring

Description

Linoleum flooring consists of linseed oil, cork, wood flour, rosin binders, and dry pigments, mixed to form a homogeneous material and calendered onto a jute canvas, felt or fiberglass backing.[8] As an installed flooring system it includes linoleum, adhesive, substrate, and optional heat welding rod. It is sold in sheets or tiles. A linoleum tile flooring assembly may also include an asphalt felt layer between the subfloor and the linoleum. Once a commonplace flooring material manufactured throughout the United

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States for use in residential, commercial, and institutional construction, it is now made only in Europe. Its place as a flooring of choice was eclipsed by vinyl composition flooring. Linoleum is making a limited comeback, in part due to its marketing as an environmentally friendlier alternative to VCT.

Linoleum costs between $2.20 and $4.00 installed; its life expectancy is from 20 to 60 years.

Summary of Environmental Issues

Linoleum is made of mostly renewable resources. The minerals used are abundant though non-renewable. The harvesting of plant materials to make linoleum has not been studied for environmental impacts. The cork and wood flour are sometimes waste products from other manufacturing processes. The manufacturing of linoleum requires a relatively high amount of energy because the calendered sheet goods cure at an elevated temperature, requiring energy for heat. Because it is manufactured in Europe, transportation contributes about 14 percent to the total embodied energy.[9] Linoleum itself has an acceptable IAQ profile, although the typical adhesive recommended by a major manufacturer is a medium, rather than low, VOC emitter. Some manufacturers recommend against installation of linoleum on slabs below grade; studies show that interaction with residual moisture can result in IAQ problems. These can be avoided by following manufacturer's installation instructions. A vapor barrier may be called for in some circumstances. Maintenance for linoleum is similar to VCT. Linoleum is said to be biodegradable, but is unlikely to do so in a landfill, where it is customarily disposed of. There are no recycling programs for used linoleum.

Carpet

Description

Carpet is specified for its resilience, warmth, and appearance as well as its acoustical properties. In the United States, many new elementary school classrooms are carpeted. In secondary schools, carpeting is usually reserved for administrative areas, media centers, and a limited number of other program areas. The use of carpeting has been reduced from a high point in the 1970s of up to 75 percent of floor area to 8-35 percent in the 1990s due to lifecycle concerns, including IAQ and maintenance issues.

Carpeting for schools is typically made with nylon. Nylon face yarns are primarily produced from petroleum. Recycled polyethylene terepthalate (PET) is used by some manufacturers for carpet fibers, but this product is usually reserved for residential applications and is said to be less durable than nylon. Although some architects specify wool carpeting for schools, its first cost, potential allergenic effects and limited durability seem to be prohibitive. This bulletin covers nylon carpeting only. Dyes may include inorganic or metalized organic compounds or acid dyes. Backings typically include both polypropylene and styrene butadiene resin. Adhesives may be of several types; the most common are organic solvent-based styrene butadiene (SB) rubber.[10] A separate pad is not typically specified for school projects.

A typical nylon carpet installation costs between $2.20 and $3.00 per square foot; its life expectancy is from eight to twelve years.

Summary of Environmental Issues

Nylon carpeting is made from non-renewable resources. Sources cite the wastes generated during production of styrene butediene (SB) latex and during the fiber dyeing process as environmental concerns.[11] Production of SB latex has been a major environmental concern, with nine of fourteen plants that produce SB latex listed in the EPA "List of Potentially High Risk Plants".[12] Based on computer modeling of estimated cancer risks, these plants could pose an unacceptably high risk of cancer in surrounding communities. The industry has improved performance in recent years, but the extent to which the risks may ultimately be reduced is not clear.

Carpet dyeing poses risks to water quality. The dyes and their wastes can deplete oxygen for aquatic life in surface waterways and may include toxic materials such as heavy metals. Solution dyeing is more environmentally friendly than other dyeing methods. Some carpet manufacturers are improving the dyeing processes, including recycling raw materials.

Environmental concerns at the installation phase involve emissions of VOCs including those from adhesives. VOC emissions from carpeting have been the subject of intense scrutiny and controversy over the last few years. Typically, most VOCs are emitted from the backing, adhesive, and seam sealer rather than from the wear layer. Emissions from adhesives tend to fall off relatively quickly. There are successful low-VOC-emitting adhesives, which substantially reduce VOC exposure significantly both during and long after installation. These currently cost about 5 percent more than conventional adhesives and are gaining wide acceptability among manufacturers, specifiers, and installers. In addition, at least one manufacturer has developed a carpet system where carpeting is attached to the substrate without adhesives by means of a hook and loop fastening system.

The Carpet and Rug Institute has established a voluntary testing program for TVOCs as well as three specific compounds that have been implicated in health issues. These compounds are formaldehyde, 4-PC, and styrene. These tests and the resulting certification applied to passing carpets may be of use in specifying carpets. A Maryland State Department of Education (MSDE) technical bulletin cautions that CRI certification "does not provide information on comfort and health effects of specific VOC emissions [and] *should not be misunderstood to assure a safe product.*"

Old carpeting may pose more health risks to its occupants than new. Microbial contamination resulting from water infiltration or inadequate cleaning procedures is a frequent problem. Fungi and dust mites are two contaminants that can trigger allergies or cause illness in a significant number of people.

More than 60 percent of new carpeting is ordered to replace existing carpeting, which then becomes demolition waste. The nylon wear layer of most carpeting in schools is a thermoplastic polymer and therefore could be melted down and reused. The difficulty lies in separating it from its backing layers. One company reclaims carpet made from its nylon, shaves and melts the face fibers, and recycles them back into new carpet. Other technologies are under development to recycle for new carpet or other materials, or to burn the carpeting for energy recovery.

Terrazzo

Description

Terrazzo is a family of flooring materials that incorporates natural marble chips and other aggregates in a cementitious or epoxy mixture, which is usually applied wet and allowed to cure in place. As a system, terrazzo flooring consists of the terrazzo mixture, with or without an underbed, poured over a concrete slab. Cementitious terrazzo requires joints, which are typically articulated with metal divider strips. After placement and curing, the surface of the terrazzo is ground and polished to a sheen.

Terrazzo can be made in several different formulas, which fall into two main types: cement-based and epoxy-based. Both feature domestic or imported marble (70%), which is selected for color and crushed to specified sizes. The cement or epoxy act as the binder; each has different sources, properties, and environmental characteristics.

Terrazzo costs between $5.00 and $10.00 per square foot to install, and will last the life of the building.

Summary of Environmental Issues

The minerals used in cementitious terrazzo, though widely available, are finite and non-renewable resources. The binder in traditional terrazzo is portland cement composed of limestone, silica, alumina, iron, gypsum, and clay, and using coal or natural gas energy sources. Mining operations for these minerals disturb topsoil, surface and groundwater, and may cause loss of habitat and degradation of local water supplies unless corrective measures are taken. Epoxy terrazzo, sometimes called "thin-set" or resinous terrazzo, uses a petroleum-based resin called epichlorohydrin bisphenol A, modified by pigments, calcium carbonates, plasticizers, extenders and defoaming agents, and combined on site with an aliphatic amine hardener to bind the marble chips together.[13]

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The marble crushing operations use water to reduce dust, and are subject to environmental and Mining Safety and Health Administration (MSHA) regulations.[14] Portland cement uses considerable energy in its manufacture. Epoxy terrazzo is a petroleum-based product, which is a finite and non-renewable resource.

The two types of binders used in terrazzo flooring raise different environmental issues during installation. Cementitious terrazzo is composed of inert ingredients mixed with water. The primary installation hazard is inhalation of dust during mixing and grinding. Water is used as a coolant during grinding and may reduce dust. Some grinding equipment is equipped with a vacuum to collect dust. Respirators must be worn by workers to protect them from nuisance dust, and the work area should be separated from occupied areas of the building. Exhaust must be directed outside without passing through mechanical system ductwork.

Epoxy terrazzo installation requires the use of OSHA-approved respirators, protective gloves, and safety glasses. Ventilation should be 100% fresh air, with no circulation of air into occupied spaces. OSHA PELs and/or ACGIH/TLVs have been established for nine of the ingredients in the epoxy matrix.[15] The waste from ground epoxy terrazzo has been tested and found to be non-hazardous.

Once cementitious terrazzo is cured, it is thought to have no IAQ impact. IAQ studies for epoxy terrazzo have not been undertaken. Because traditional cementitious terrazzo has a long track record, and because it is basically ornamental concrete, its IAQ characteristics appear to be less of a concern than the epoxy-based terrazzo.

Terrazzo flooring must be sealed to prevent absorption of dirt and stains. Water-based sealers are available and widely used. There are no programs for recycling terrazzo.

Wood Flooring

Description

Wood flooring, once the material of choice for classrooms, now is specified for schools only where its performance characteristics make it uniquely desirable: gymnasiums, stages, and dance studios. Wood flooring used in schools typically consists of hard wood strips. For gymnasiums and dance studios, the strip flooring rests on a sleeper system over a concrete floor slab. The finish for the wood includes paint, stain, sealer, and clear topcoat. Today, synthetic flooring materials compete with wood flooring even for these limited uses.

The primary ingredient in wood strip flooring is wood from trees. Sleeper systems may be made of steel with synthetic components or may be wood. Finishes can be solvent- or water-based, each type has different environmental properties. Wood flooring can be made from a variety of tree species. Older schools may have wood floors from maple, oak, or even softer wood such as pine. Today, most wood flooring specified for schools is maple, due to its hardness and durability.

Wood flooring costs between $6.00 and $10.00 per square foot. Its life expectancy averages 38 years, but may last much longer.

Summary of Environmental Issues

Materials acquisition starts with the harvesting of trees. The timber industry and the environmental community have often been at odds over forest management practices; yet lumber remains an important material in construction and has positive environmental properties. It is low in embodied energy and is a renewable resource. Its environmental performance hinges on its growth and harvesting practices.

This can be difficult, if not impossible, for a specifier or flooring installer to evaluate: finished lumber can be difficult to trace back to its location of origin, and environmentally sound logging practices are not readily apparent. Both industry groups and third party groups have developed programs to encourage improvement of forest management practices in response to public concern. Industry efforts attempt to bring most manufacturers up to a minimal level of performance and third party groups have begun certification programs for wood. Several producers of hardwood flooring have been certified as having sustainably managed forests.

The positive environmental practices that forestry certification programs look for may include:

- **Long term forest management plans**
- **Rotation of logging through different areas**
- **Minimal logging damage to remaining stands**
- **Maximum regeneration potential**
- **Reforestation or provision for natural regeneration**
- **Maintenance of a cohesive natural forest ecosystem**
- **Use of several tree species from an area**
- **Use of wood waste**

Availability of maple flooring has not been quantified, however long lead times for large orders are the norm, in part due to resource availability.

The protective finish coats, if solvent-based, may be high VOC-emitters. Solvent-based emissions may continue after installation for an extended period of time. Clear coats may emit formaldehyde. Low VOC finishes are on the National Flooring Manufacturers Association's list of approved finishes, and are recommended as a significant improvement for indoor air quality.

Because of its synthetic topcoats, wood floor maintenance is similar to VCT or terrazzo in maintenance practices. A typical hardwood floor might need resanding every eight to ten years and can be resanded up to five times. Annual screening and recoating maintains the protective wear layer. Some installers feel that water-based finishes may not be as durable as oil-modified formulas, but the water-based finishes are gaining wide acceptance. Wood flooring is easier to repair than many other materials.

Wood flooring is recyclable and the market for recycled wood flooring is expanding. The primary material, wood, is biodegradable.

Ceramic Tile

Description

Ceramic floor tile is made of clay, silica, limestone, talc, and feldspar.[16] These are formed into tiles which may or may not be glazed prior to firing. The finished tiles are installed on a bed of mortar, then grouted and sometimes sealed. Mortar is made of sand, lime, and portland cement. Pigments come from a variety of mineral sources. Additives and abrasives are typical. Mosaic tiles are usually held together by a plastic mesh backing. Ceramic tile is used in toilet rooms, kitchens, and occasionally for lobbies and other high-traffic areas.

Ceramic tile costs between $6.00 and $12.00 per square foot installed. Its life expectancy is from 40 to 80 years.

Summary of Environmental Issues

The raw materials for ceramic tile are non-renewable, although most are in abundant supply. Open pit mining can lead to air emissions, habitat alteration, and erosion. Energy requirements for ceramic tile are high, due to the heat requirements for firing the tile. Latex-based mortars and grout may pose IAQ problems. Cementitious mortar and grout are not thought to be sources of air emissions. Some companies manufacture tile from recycled materials. One product is made primarily of recycled airplane glass.

Maintenance for ceramic tile varies with the type of surface and grout. Most unglazed tile is sealed after installation. There are no programs for recycling used ceramic tile.

A Hypothetical Material Selection Process

A school district is planning to renovate and expand an existing elementary school. The original school predates the Second World War; it has wood floors in its classrooms and terrazzo floors in the halls. An educational specification team, lead by the local board of education's facility planner and the project architect, are determining program requirements. The architect at first expected to cover the wooden floors and finish all new floors with VCT. After developing a flooring selection matrix based on the criteria established above, the committee came to some different conclusions.

The committee decided to sand and refinish the existing wood floors. Early childhood spaces, where a warm, soft surface is important, will receive a

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Figure 3. Flooring Selection Matrix

Criterion	A	B	C	D	E	F	G	Total
Material	Raw Materials	Embodied Energy	TVOCs	Life Expectancy	MSDS	Lifecycle Cost	First Cost	Points
VCT	1.5	3	2	2	3	3	4	18.5
Carpet	1.5	1	1	1	3	1	3	11.5
Linoleum	2.5	2.5	2	3	4	3	3	20
Cementitious Terrazzo	2	N/A (cement=3)	4	4	4	3	1	21
Wood	3	1.5	2.5	3	4	3	1	18
Ceramic Tile	2	2	4	4	4	3	1	20

moderately sized (16'x16') bound carpet that will not be adhered to the floor. That way it can be easily conditioned prior to installation and removed when necessary for cleaning or replacement. The existing terrazzo floors were still in good condition. The addition to the school will be finished with terrazzo in the new hallways. Linoleum was the committee's first choice for the new classrooms, but because of its higher first cost it will be bid as an alternate. The base bid will include VCT. No adhered carpeting was specified for any student-occupied spaces.

This hypothetical example illustrates decision-making process based on a flexible understanding of goals and realities. The example also shows that the long-term savings inherent in investing in durable materials with higher first costs is sometimes difficult to realize in practice because budgets for the building and operating of schools are distinct.

Improving Building Ecology for Schools

Building ecology is broad in outlook. Unlike commercial design, where the initial developer is not the ultimate occupant, school design typically unites developer, owner, and occupant. Therefore costs that are external to commercial design are internal for school systems, local governments, and the taxpayers who support them. The possibility exists for facility planners to consider first costs, operating and energy costs, teacher and student performance, landfill and incineration, and other relevant issues.

General Recommendations

- Develop school projects within a master planning process that recognizes the value of existing facilities.
- Plan for more than the typical forty years of useful life from a facility.
- Emphasize durability in the decision-making process by considering life expectancy and amortizing first costs, resource use, and embodied energy over time.
- Select the most environmentally beneficial approach within the limits of performance requirements and available information. Where judgement calls are made, consensus-building and local priority-setting are keys to sound decisions.
- When possible, choose local materials. Locally acquired and produced materials minimize transportation costs while benefitting the local economy.
- Consider the synergistic effects, both positive and negative, of materials in the context of the whole project. An example of a negative synergistic effect is the VOC adsorption properties of some materials. An example of a positive synergistic effect is a material's heat sink capability that can reduce heating costs.

Recommendations for Flooring Selection

- Highly durable materials are justified, especially for high-use areas, based on life-cycle costs.
- Adhered carpet systems are not recommended for most areas; they require a high level of maintenance that is often not available, and their need for frequency replacement makes the resource-and energy-intensive over time. Alternatives include bound carpet for early childhood classrooms, carpet attached with loop fasteners or other temporary means, or resilient flooring.
- For terrazzo, cementitious rather than epoxy systems appear to have less significant environmental impacts.
- For ceramic tile, portland cement-based, rather than latex- or solvent-based mortar and grout, appear to have less significant environmental impacts.
- For vinyl flooring, use VCT rather than sheet vinyl.
- Wood flooring from sustainable forests may be an appropriate flooring material for more functions, including classrooms, than it is currently specified for, especially in regions where desirable species are native.
- Consider maintenance materials and processes as an integral element in the selection process.

Recommendations for Flooring Installation and Maintenance

- Where solvent-based or other "wet" materials are used, specify an airing out period, where 100 percent outside air is circulated through the installation area without sending exhaust air through adjacent spaces and ductwork. Length of airing out should be determined based on VOC emission curve. Seventy two hours may be adequate for carpet, linoleum, and VCT when low-VOC adhesives are used; solvent-based systems may require more time. Delay occupancy by students for at least 72 hours after installation. VOCs may continue to be an issue for longer periods, but specific product-by-product data are needed to weigh the benefits of a long flush-out period and further delay in occupancy.
- Install porous materials, such as carpeting, last, as these may act as sinks and adsorb VOCs from nearby materials and re-emit VOCs over a period of time.
- Where adhesives are required, specify low-VOC products. Use the smallest amount of adhesives that can do the job, within manufacturers' recommendations.
- Ask manufacturers if they will accept waste from flooring installation. Some materials could be recycled into new products at this point.
- Collect MSDSs for recommended sealers and cleaning products along with material submittals. Select materials only where non-toxic and low-VOC maintenance products and procedures are available. Incorporate this information in the project manual.

Summary

Building ecology is a relatively new concept for most school planners and architects. There are no miracle materials, and environmental impacts are proving challenging to quantify and quantify. But even within these limitations, there are several levels of improvement on the horizon. First, many manufacturers have already made real improvements in the environmental performance of their products. It is often unnecessary to abandon comfortable materials; instead concerns and specifications for improvement can be discussed with manufacturers. Second, the vocabulary, test methods, and standards are becoming more uniform. Comparisons that are difficult to evaluate this year will be easier next year because of efforts like the NIST database. Third, new materials and new ways of thinking about old materials, architecture, and building ecology are emerging.

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